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Geotechnical Lessons Learnt From Neftegorsk Earthquake

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GEOTECHNICAL LESSONS LEARNT FROM NEFTEGORSK EARTHQUAKE

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ABSTRACT

Under Neftegorsk (North Sakhalin) earthquake (1:04 a.m. local time, 05.28.95) 17 residential large-block houses were fully collapsed and killed almost everybody of inhabitants. Most of investigators explain this tragedy by poor construction. Other cause related to soil condition is under consideration. The author argues that "soil version" is more reasonable and significant than "construction version".

Neftegorsk is located on the sand deposits and just inundated sands, which were in basement of the 5-story buildings and had a liquefaction ability, could provoke a rapid inhomogeneous buildings settlements under vertical earthquake component.

Thus, the absence of forehanded geotechical analysis under new seismic hazard conditions has resulted in soil liquefaction and subsequent structural collapse.

INTRODUCTION

The earthquake in Neftegorsk was the next (after Kobe) great disaster event of 1995.Insidentally, from nearly 2000 victims 90%were killed under collapse of all 17 uniform 5 storey large-block houses of 447-standard. The complete collapse of all houses of this constructional type (Fig. 1) and death of more than 70 % of their inhabitants is a flagrant example in the history of modern construction. Notwithstanding the fact that when being designed such houses were not intended for construction in seismic regions , their mass collapse was statistically unaccountable. According to DIMAK Scale – Scale of Disaster Magnitude - (Klyachko, 1993) the Neftegorsk EQ is estimated as "a great disaster of national scale" (Md=4.53), and an index of relative social vulnerability is calculated as p=1.06, i.e. very high social vulnerability. The search of reasonable explanation in this connection is likely to prevent similar seismic tragedies and to select a correct approach to the use of such large-block houses built on the seismo-prone areas.

ANALYSIS

The identical collapse of all 447- standard houses can be explained only by revealing of some general (inherent only in such structures or construction site) cause factor (or a group of factors). The attempts of most researchers (Eisenberg,1996, Koff,1995) to give as such factor deteriorated building materials of pool quality (ceramsite concrete blocks of exterior bearing walls, etc.) are not enough reasonable and convincing.

Fig. 1. 5-storeyed large block houses (damage degree d=5, full collapse).

It is unjust to attribute to lowest value of ceramsite concrete strength (2.5 MPa instead of 7.5 MPa design value) found only in one lintel block to other wall blocks and reinforced concrete products of all 447-standard houses. Moreover, light damage of other apartment houses built also ignoring antiseismic measures, the building of a polyclinic and a kindergarten made of large ceramsite concrete blocks (Fig. 2) confirm indirectly unfitness of the "constructional version" as the main cause of Neftegorsk tragedy.

Fig. 2. Two – storyed large block houses (damage degree d=1).

Main results of post – earthquake field investigations are shown in table 1. This underlined again that soil conditions under buildings are similar.

Table 1. Overview of constructional aftermath of Neftegorsk earthquake

Index	447-standard houses	Other large-block houses	RC frame buildings	Masonry	Wooden frame houses
Type of construction	B1	B1	G4 G3	A0 A1	D
EMS vulnerability class	B	C	C	B-C	C-D
Degree of damage (d)					
5	17	-	1+1	3	-
4	-	-	-	1	-
3	1(polyclinic)	-	2	-	-
2	-	4+1	1	4	-
1	-	2	-	3	15
0	-	-	-	-	65

Note: Type of construction is given in accord with (Klyachko,1987).

The Japanese scientists (Kadami,Ishiyama,1995) believe that local soil conditions did not produce an essential impact on the intensivity of seismic oscillations, and, hence, on the damage of structures under Neftegorsk earthquake.

As there are no records of the Neftegorsk EQ we cannot analyze in detail the dynamic soil-structure interaction. We should only draw attention to the fact that the 447-standard houses had periods of natural oscillations T=0.43s, that is much higher as compared with other, lower and more rigid structures in Neftegorsk.

Still retaining some "constructional" causes of collapse we cannot but consider another main version - a soil one.

Soil base of Neftegorsk buildings and structures presents on the whole sands with gravel inclusions (10-20%). In the upper stratum the sand is silty (more seldom - fine), moist (more seldom - saturated); at the lower level the sand is primarily fine, saturated. The subterranean water table (WT) ranges significantly (depending on the season and place) from 1.5 to 6.0m of a surface.

Soil laboratory tests were not carried out under survey, and table values (Supplement 2 to S.U. Building Code "SNiP B.2-62") were adopted as the design characteristics which gave a rather reliable description of static characteristics of sand soils in the base of structures, namely:

- density (at natural moisture contain w=0.18%) ρ=1.85g/cm^3;
- dry density ρ_d= 1,63g/cm^3;
- soil particles density ρ_d=2.66 g/cm^3;
- void ratio e=0.64 (middle density);
- moisture degree Sr=0.58 (moist);
- angle of internal friction φ=30-37^0;
- cohesion c=4.2kPa;
- modulus of deformation E=18.5MPa.

During design and the main construction period (until 1971) anti-seismic specifications were absent, as the construction site was considered to be of low seismicity. The design constructional treatment of the 447-standard collapsed houses is described in (Klyachko,1998). It is also necessary according to the European Macroseismic Scale (EMS-97) to add generalized estimates of regularity (R) and quality (Q) of the analyzed structures. In accord with EMS-97 scale and the existing practice one should estimate R and Q by the lowest level:R_1 and Q_1, i.e. by the value wide-spread in european countries. Meanwhile one should note the Noglik EQ (M=5.8) which occurred on October 2,1964 (construction period) and had intensity I=7-8 in Neftegorsk. However a seismic code didn't change a design seismicity and Neftegorsk was considered a practically aseismic area!

More interesting can be not the analysis of the standard design but of the design treatment with adaptation of the standard projects— the stage during which configuration and basic constructional decisions must not be changed. Here designers gave their treatment of the arrangement of the bases and foundations of the structures taking ready loads on the level of the upper cut of a foundation. According to the initial design the houses must have had basements but the engineering survey carried out in summer showed that the WT was lower than 5-6m, therefore the traditional construction was selected - a strip foundation of precast concrete elements. This construction suited contractor building agencies aimed at. total industrialization. The variant with a piles foundation requiring pile-driving equipment and, mainly, a monolith pile grating, was declined.

The first houses were erected in 1964-65 strictly according to design - with basements but it turned out that during the season of maximum WT foundation trenches were flooded with water, and that interfered with the works. One cannot but consider the strict requirement used to exist during design and construction -to get the possible efficient decision as far as the consumption of the principal building materials is concerned. In our case this requirement expressed itself In the intention to make cheaper $1m^2$ of a living area in some 447-standard houses by removal of basements. The arrangement of basement storeys in residential houses of urban-type settlements was forbidden by the Codes at that time and was permitted for rural areas only and designers had to face a dilemma: either to remove basements or develop Neftegorsk as a country-type settlement, but in that case 5-storey houses had no right to exist, and one should have reduced a number of storeys. Thus, there were all objective causes for approval of the proposition: to remove basements and to raise the mark of foundations bottoms "having dragged" them out of the water.

Estimating the decision taken under design of the soil bases and foundations one can today with confidence confirm its reliability and efficiency under the loads of main and special combination in the conditions of regular use. The load on a strip foundation at the level of its bottom is estimated approximately at 26t/m for exterior longitudinal axes "A" and "B", and 35t/m - for a medium axis "B". At the bottom width of 1.2 and 1.4m relevant pressure on the soil under the foundation bottom constitutes 220-250kPa, that is somewhat lower than allowable design resistance of the sand soil recommended by the Manuel (1986) (proceeding from R_o= 150 kPa) and adopted by designers.

Under design of structures the following averaged characteristics of sand soils at the depth of 2m from a planning surface were adopted; c=4 kPa;-φ=30-37°; F=18.5MPa. Here the minimum value of the angle of internal friction corresponds to silty sand of medium density (Tabl.26, Manuel,1986). Static and dynamic soil sounding was not performed, therefore we can find index relevant to the conditions: q_c=3 MPa q_d=5.5 MPa (disregarding water saturation) using Tabl.21 and 23 (Manuel,1986). These values also correspond to Tabl.10 (Manuel,1986).

In case the upper value φ=37° is admitted it corresponds to the very high value of q_c=15MPa , and this correspondence is not characteristic of silty and fine sands but of coarse ones. Thus, over the range from 37° to 30° the indices of static sounding q_c decrease from 15 to 3MPa, and at transition from fine to silty sand the value of deformation modulus E decreases not less than 1.5 times even if not taking into account water saturation of such soils.

In soil bases composed of incompletely saturated silty sand (in this case $Sp=\omega p_s|ep_\omega=0.58<0.8$) the following processes take place: extra water saturation, increase of soil moisture content and reduction of soil strength and deformity characteristics (design soil resistance decreases from 250-300 to 100kPa). That is the very "A" factor neglected by designers – the result of ignoring of seasonal and technogenic increase of WT in fine and primarily in silty sand. However, under loads of general and complementary combination the limit balance in consolidated sand enabled to provide safe use of the buildings.

The additionally neglected "B" factor was a dynamic quick increase of pressure on sands under the foundation bottom excessing the design value twofold due to vertical EQ-component estimated by PGA of up to 0.8g. The joint damage-forming impact of the two important factors "A" and "B" was manifested as vibro-settlement in the most stressed place - under the foundation bottom of the medium bearing wall of the 5-storey building. It is exactly the combination of "A" and "B" factors characteristic of 447-standard houses that was the main cause of the Neftegorsk tragedy. Such effect in 2-3 storied buildings was not noticed (Fig. 2).

The "soil version" which gives explanation of the causes and mechanisms of the collapse of the 447-standard 5-storey houses is confirmed by the following facts:

- only 5-storey houses collapsed completely and identically; houses of lesser number of storeys with a small values of pressure on the soil under the foundation bottom did not suffer from damage ;

- collapse of all seventeen 447 – standard houses happened in one and the same way - inwards, resulting from vibro-settlement of the foundation of the medium wall (axe B); according to the data of population inquiry the seismic impact was represented by 2 successive short heavy shocks: upwards and sidewards;

- the author found the made "on ground" floors of the ground floor storey demolished upwards by EQ-shocks;

- physical evidences of liquefaction such as sand boiling and lateral flow of ground were noticed outside Neftegorsk closely to EQ-epicenter. Liquefaction was an indisputable cause of damage of railways and bridge supports;

-sand soils in "floating earth" state were found after the earthquake in the control borehole near the damaged building of the club.

The above data seem to be very close to truth, however, one can not but remember that until now complete field and laboratory engineering and geologic survey in Neftegorsk has been absent, therefore one should study particularly carefully national disasters to correct the mistakes of yesterday, not to permit their recurrence today and to prevent the tragedies of tomorrow.

CONCLUSIONS

Geotechnical lessons learned from Neftegorsk EQ are:

1. The collapse mechanism of 5-stored buildings is explained by flash settlement of middle bearing longitudinal wall due to the simultaneous reducing bearing capacity of saturated silty sands and to almost doubling load on the foundation under vertical EQ-component.

2. The engineering geology survey has not been complete and sufficiently carried out from the viewpoint of both volume and quality of survey.

3. Designers and contractor have not taken into account and have not put into practice a real seismic event (I=7-8) occurred on Oct. 2, 1964 near Neftegorsk.

4. The designers have not paid an attention at the possible consequences of inundation of silty sands, although they could do it on the basis of present knowledge and soil property decription. However, a bearing capacity of sand basement was sufficient for static behavior of building (safety coefficient was about 1.2).

5. One should note that this EQ would have beennot so disastrous if designers have chosen a pile foundation instead of strip one. This decision could a building's collapse.

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